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RFID associated to Ambient Intelligence and Multi-Agent Systems for Warehouses Decentralized Management and Control

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Abstract

RFID associated to ambient intelligence provide the basic interconnected network infrastructure for decentralized warehouses management and control. In this paper, we discuss benefits and barriers of decentralized approaches and how they can be adopted in warehouses. We examine mechanisms, protocols and architectures that can be used for warehouse decentralized control. Finally, we propose a warehouse architecture based on decentralized approach for warehouses order fulfillment process. This architecture associates RFID technology with ambient intelligence platform and multi-agent system.

Key words: Warehouse, Decentralized Approach, Multi-agent System, RFID, Ambient Intelligence.

1: INTRODUCTION

Industrial applications using a decentralized control approach remain extremely rare and the implemented technologies' functionalities are usually restricted, owing to their very slow and limited adoption in industry (Mařík and Macfarlane, 2005; Leitao and Vrba, 2011). One of the main barriers to adoption is related to the high investment required to implement these emergent approaches, which is much greater than that required to implement a conventional solution (Leitao and Vrba, 2011). Recently pioneer companies such as Walmart, Metro, and Procter & Gamble have undertaken large scale implementation of RFID technologies (Sarac et al., 2010). The potential benefits resulting from these supply chain deployments include cost reduction; value creation related to inventory accuracy, diminished bullwhip effect and improved replenishment policies. RFID infrastructure provides the basic interconnected network infrastructure for decentralized control approach. In the present paper, RFID infrastructure consists of tags, readers, sensors and RFID software. Research in warehouse management and control using decentralized approaches are significantly lacking. Therefore, in this paper, we first discuss benefits and barriers of decentralized approaches and how they can be adopted in warehouses. Then we examine mechanisms, protocols and architectures to be used for warehouse decentralized control. Finally, we propose warehouse platform architecture for order fulfilment process in a dynamic environment based on a Multi-Agent System, ambient intelligence and RFID infrastructure.

2: INDUSTRIAL ADOPTION OF MULTI-AGENT STSTEM

Industrial adoption of agent-based technologies has already been discussed in several papers Marîk and Macfarlane (2005) identify barriers and benefits for using MAS in dynamic and complex industrial environment. They consider feasibility, robustness, flexibility, and reconfigurability as the main benefits of using multi-agent systems in industry. Likewise, they highlight barriers as including costs, operational performance, scalability, commercial platforms, engineering education, design methodologies and system performance. Weyns et al. (2009) stresses that, embedding agent-oriented software engineering in software architecture provides opportunities to amplify industrial adoption of MAS. Finally, Leitao and Vrba (2011), consider that distributed thinking (centralized and hierarchical oriented), investments and industrial maturity of Agent technology are the principle reasons for the weak acceptance of this issue in industry.

Recent advances in RFID technology and ambient intelligence platform have enabled the development of open and reconfigurable network architecture. These technologies provide the main characteristics of interconnected structure such as product auto-identification and resource auto-configuration. Also, we can add the fact that industrial deployment of an RFID infrastructure ultimately reduces investment costs and justifies ROI (Return On Investments) (Friedlos, 2008; Kim, and Sohn, 2009). In logistics, ambient intelligence was associated with RFID technology to enhance warehouse business processes and to perform transparent interactions with products handled throughout the supply chain (Kim et al., 2008; Bajic, 2009). Typical warehouse management processes is realized through application software packages such as Enterprise Resource Planning systems (ERP), Warehouse Management Systems (WMS), Transport Management Systems (TMS) and Advanced Planning and Scheduling (APS) softwares (Helo and Szekely, 2005). These tools are not able to cover satisfactorily the constraints required by warehouse management and control in terms of customer satisfactions and system costs (and profits) in dynamic and complex system like urban distribution centers and logistics city.

Otherwise, we agree that bottom-up or dynamic approaches are considered as the most suitable for warehouse management and control in dynamic environment (Reaidy et al., 2012). They are autonomous and consider multi-agent interactions. This concept provides suitable, adaptable and robust solutions due to improving self-organization resulting from interactions between interconnected networks (Adam et al., 2011). This concept is totally different from the conventional approach. An example of this is the system of auctions and negotiations between agents that indirectly (and organically) generates real-time scheduling, thus rendering the unneeded position of scheduler. This contrasts intelligence generated by a conventional approach which is quite localized at the process level. So, extended bottom-up intelligence can be distributed at product, environment and process levels or distributed at process and logistic/interaction levels (Massotte et al., 2003). Research in warehouse management and control using decentralized approaches are significantly lacking. RFID associated to ambient intelligence and agent technologies provide development of an ideal platform for decentralized management and control of warehouses in dynamic environment. This opportunity encourages researchers to develop and refine practical solutions to the industry by developing self-organizational mechanisms to improve responsiveness, adaptability and robustness of the platform. This perspective allows accelerating the adoption of these technologies in industry.

3: DECENTRALIZED APPROACH TECHNOLOGIES FOR WAREHOUSE MANAGEMENT AND CONTROL

Decentralized approach for warehouse management and control associates technologies and platforms providing a self-organization behavior and interconnection networks between all warehouse entities (such as products, resources and information technology infrastructure). Multi-agent systems are considered as the most suitable technologies used for insuring self-organization behavior in dynamic and complex systems. Agent technology using self-organization principles has been positively applied to numerous application domains: simulation, manufacturing, logistics, network management, collective robotics, flood forecasting, and biological modeling (Bernon et al., 2006; Leitao and Vrba, 2011).

Likewise, ambient intelligence or ubiquitous computing provides interconnected systems and services in the surrounding environment to support activities and actor's interactions (Riva, 2005). Thus, it was applied in trade, logistics, industry, transport and healthcare, as well as personal identification (Friedewald and Raabe, 2011). We can notice that Multi-Agent System (MAS) was successfully associated with the ubiquitous environment in logistics, production, mobile hardware and healthcare (Jedermann and Lang, 2008; Poon et al., 2009). Indeed, agents offer features that are much sought by ambient intelligence architecture, like reactivity, autonomy, pro-activity, the possibility of reasoning and anticipation (Ramos et al., 2008). We can also mention that decentralized control approach structure was proposed in manufacturing control systems for resource allocation problems. It associates MAS with RFID technology and ambient intelligence platform (Fletcher et al., 2003; Bratukhin et al., 2006).Warehouse allocation problem can be modeled as a job shop sequencing problem (Zäpfel and Wasner, 2006). RFID associated to ambient intelligence provide the basic interconnected network infrastructure for decentralized warehouses management and control.

Otherwise, the adoption of MAS in dynamic warehouse management and control provides many benefits, one of the first significant benefits of MAS adoption in warehouse management and control is the global performance satisfaction. The second benefit is the improvement of the reliability of order management and fulfillment. This can be satisfied by the fact that order accuracy, order on-time rates and order completeness will be improved by interconnecting RFID technology to system agents. The third benefit is the tailoring of warehouse management costs depending to depend by mastering inventory costs, reducing handling and inspecting, including priority rules, etc. Other benefits can also be mentioned, as the mitigation of internal warehouse risks, the mastering of demand variability, the improvement of customer satisfaction. In the next section, we propose a warehouse platform architecture based on a dynamic approach for order fulfillment management and control.

4: WAREHOUSE PLATFORM ARCHITECTURE

The Warehouse platform architecture proposed associates RFID technology with ambient intelligence and multi-agent system platforms. It can be discussed in four different layers, as shown in Figure 1. The physical devices layer consists of all the physical, embedded devices (i.e. pallets, forklifts, packing machines, trucks).

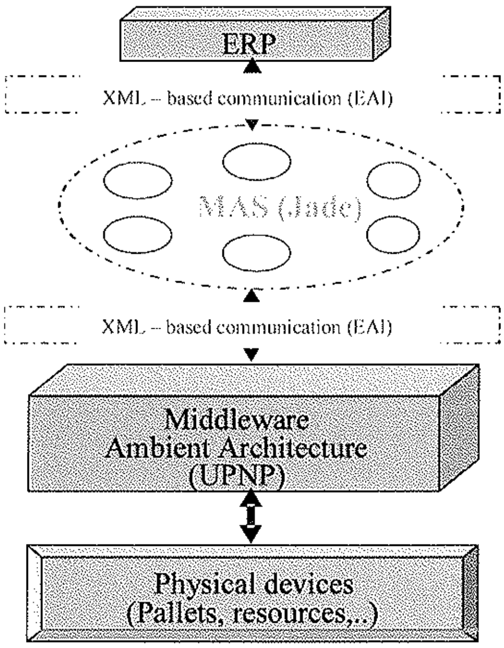

Figure 1. Warehouse platform architecture

Pallets use passive RFID tags. The information stored in the tag is transmitted to the ERP via the UPnP middleware. Forklifts, trucks and packing machines will use ambient intelligent platform to identify pallets and to exchange information with it. The device discovery protocol is selected to implement the UPnP (Universal Plug and Play) middleware layer which then interfaces with the devices. The Multi-Agent System (MAS) layer platform Jade comprises pallet agents, resource agents, control agents, and interface agents. The top-most application layer refers to all possible user interface applications and ERP. The MAS layer exchanges information with the ERP and Middleware ambient architecture using an EAI middleware and XML interfaces.

5: MULTI-AGENT ARCHITECTURES AND MECHANISMS FOR WAREHOUSE MANGEMENT AND CONTROL

In this section, we examine architectures and mechanisms used by agent for warehouse management and control. An agent is an autonomous, pro-active and smart object representing the pallets and resources in a warehouse. It can negotiate (cooperatively or competitively) with other agents and make decisions using protocols and strategies (auctions, game theory) to deal with system constraints and advance toward their own goals (delivery time) (Reaidy et al., 2012). Architectures commonly considered in a multi-agent approach encompass mainly hierarchical, heterarchical and holonic structures. In a hierarchical architecture, there are multiple levels of master/slave agent type relationships. In heterarchical architecture, agents communicate on a''peer-to-peer'' mode, without any predefined master/slave relationship. Holonic is a hybrid structure integrating both hierarchical and heterarchical architecture. Holonic structure provides robustness, self-organization and self-adaptation between agents or holons in a dynamic and complex system (Leitao et al., 2009). Fletcher et al., (2003) describe the implementation of a holonic packing cell using agent and RFID technology. Agents are based on the BDI (Belief, Desire, Intention) model (Bratman, 1987). It negotiates and makes decisions with the help of its plan library and knowledge base. Furthermore, Chow et al., (2007) propose a RFID-multi-agent based process knowledge-based system (KBS) to solve dynamic logistics process management problems. Encinas et al., (2010) propose a management system for warehouses based on MAS enhanced with RFID. They use an experimental platform composed of a 3D simulation combined with a physical miniature model developed at the University of Castilla-La Mancha in Spain. Finally, Reaidy et al., (2012) a holonic architecture for collaborative warehouse order fulfillment in a dynamic environment based on a Multi-Agent System (MAS) and RFID infrastructure. Warehouse order fulfillment process integrates several concepts and mechanisms such as self-organization and Negotiation Protocols (NP) between agents based on "coo-petition" and "com-peration" principles. (see table 1).

Table1. Agents with RFID infrastructure for warehouse management and control

Warehouses	Mechanisms	MAS Structure	Agent architecture	MAS Platform	Sources
The Cambridge Packing Cell	Knowledge base; NP	Holonic	BDI	JACK™	(Fletcher et al., 2003)
Dynamic logistics process	KBS	Hierarchical	BDI	Java	(Chow et al., 2007)
Logistics/ Distribution center	Petri nets	Hybrid: reactive, deliberative and interface level	BDI	Java, Grasp software	(Encinas et al., 2010)
City hub	NP, Solver Game Theory	Holonic	BDI	JADE	(Reaidy et al., 2012)

In this work, warehouse platform architecture associates ambient intelligence with agent technology. This combination makes the agent more intelligent and cognitive, because of the real-time connection and the automatic reconfiguration of physical entities within the environment. As we said before, agents are based on the BDI model. Agent "Belief" and "Desire" characteristics are based on perception and information received from a ubiquitous environment that identities delivery date. Agent "Intentions" will concern strategies to be used like decision making rules. In this situation, agents are hybrids (cognitive and reactive) directly responsible for piloting a functional, self-organized system. They co-create the decision and negotiation mechanisms for dynamic resource allocation with other agents. The hybrid nature of an agent is revealed by its interactions with its environment and its strategies which can include cooperation, competition, "coo-petition" and "comp-eration". "Coo-petition" is a contraction of cooperation and competition (Brandenburger and Nalebuff, 1996). "comp-eration" is the contraction of competition and cooperation (Reaidy, 2003; Zouaghi et al. 2010). Reversing the order of these two strategies creates a new, completely different principle from that of "coo-petition". Providers initially adopt a competitive strategy to ensure their individual interests. These same suppliers progressively adopt more collaborative strategies when price competition increases and production demands become more challenging. Generally speaking, an agent can and will switch from a cooperative strategy to a competitive one during its existence to satisfy its interests and achieve its objectives.

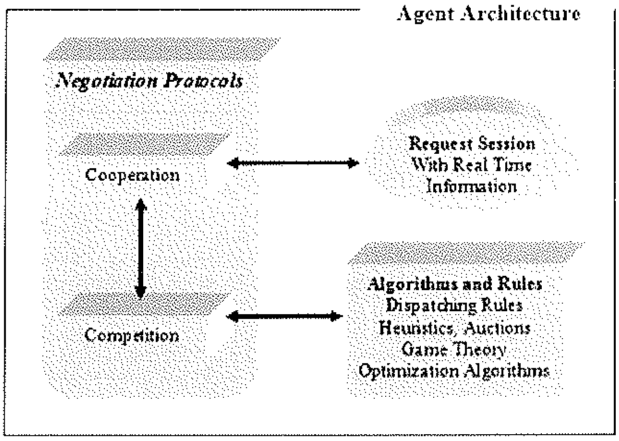

Figure 2. Categories of negotiations and decisions used by Agents

Figure 2 shows the different categories of decision that can be used by an agent in the system. As stated above, different agent negotiation protocols can be summed up as cooperation, competition, comp-eration and co-opetition. In the case of cooperation, the agents' decisions take into account other agents' priorities, when, for example, participating in a "Request Session". The main goal of the request session is to provide negotiating agents with real-time information over a given period of time before final decision making is completed, for more details see (Reaidy et al., 2006). Their decisions may be altruistic or consensual. In the second case, that of competition, decisions are opportunistic and may be based on dispatching rules such as "First-Come First-Served" (FCFS), "Shortest Processing Time" (SPT), heuristics, optimization algorithms or even on game theory. In the case of "coo-petition", the agent starts by cooperating, during a Request Session, prepares for allocation of its next task, and then completes the process with competition specific rules and mechanisms during final decision making.

6: SYSTEM MODELING APPROACHES

In our model, order fulfillment concerns only pick/pack/ship process. It is generated by an ERP system. Warehouse uses an UPnP ambient environment middleware for exchanging information between devices, ERP, and multi-agent system. Agents will represent orders fulfillment, pallets and different resource devices of the system such as forklifts, packing machines and trucks. So we consider that the process starts once an Order Fulfillment is released by the ERP to the Warehouse (see figure 3).

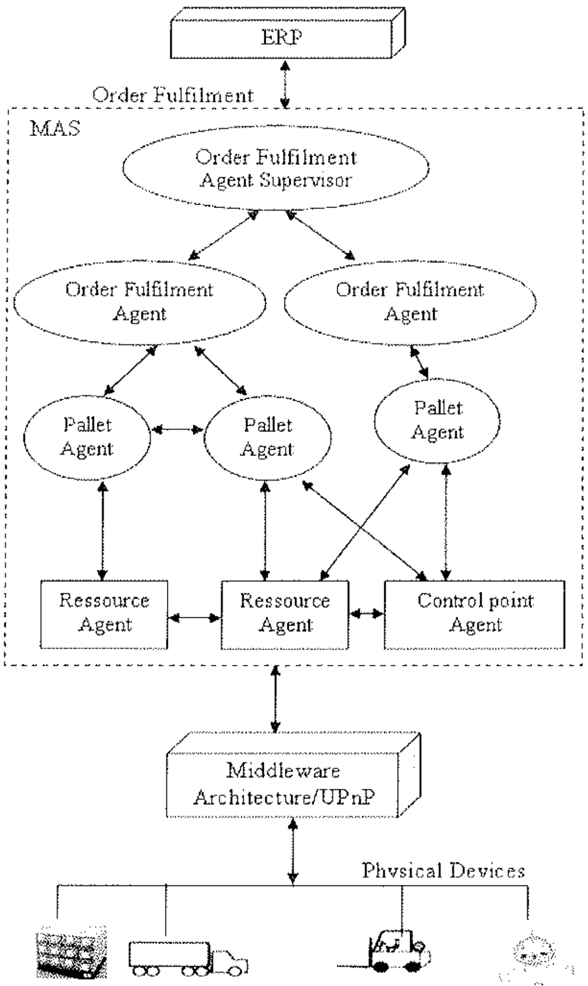

Figure 3. Multi-Agent Architecture for Order fulfillment process

The Order Fulfillment is analyzed by the Agent: Order Fulfillment Agent Supervisor. Then it creates an Order Fulfillment Agent corresponding to the Order Fulfillment. This generates a set of Pallet Agents for each Order Fulfillment. Pallet Agent is assigned to the real and physical pallet. It follows the physical pallet; it negotiates and schedules for it all its next processing tasks. Each resource is represented by Resource Agent. Tasks provided by resources concern picking, packaging and shipping. The Control Point Agent represents UPnP control point architecture. It is used to control and to communicate general information about devices location status and their services in the warehouse. Order Fulfillment Agent Supervisor is responsible for the management of Order Fulfillment Agent lifecycle. It has a connection to the ERP to receive new order fulfillment or changes and to inform about the state of running ones. The development of this platform is funded by the Rhône-Alpes ARC7 (Academic Research Communities) project.

7: CONCLUSION

In this paper, we show that warehouses decentralized management and control can be effectively performed by associating RFID technology with ambient intelligence platform and multi-agent systems. After presenting MAS industrial adoption to highlight the fact that it provide characteristics of interconnected structure such as auto-identification and auto-configuration, or also-auto-organization, we point that decentralized oriented technologies for warehouse management and control provide several benefits the improvement of the reliability of order management or the mitigation of internal warehouse risks, This has lead us to present warehouse platform architecture, which has been addressed through different layers, namely the physical device layer, the middleware layer, the MAS layer and the application software layer. Then, mechanisms for warehouse management and control concerning MAS architecture were presented, to end up with agent architecture and system modeling approach.

This model allows accelerating adoption of these concepts in industry. So, the warehouse architecture based on decentralized approach for warehouses order fulfillment process that was proposed develops and combines existing architecture layers with a middleware layer represented by a multi-agent system. This proposal encourages researchers to refine practical solutions to the industry by developing self-organizational and re-configurability mechanisms to improve robustness of decentralized control platforms. Agent-based model proposed in this work will be evaluated and validated through simulation via a warehouse platform architecture developed within the ARC7 Rhône-Alpes-funded project.

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